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HIGH COERCIVITY IN MELT-SPUN $SmFe_{10}(Ti,M)_2$ RIBBONS (M=V/Cr/Mn/Mo)

M. Okada, A.Kojima, K. Yamagishi*, and M. Homma
Department of Materials Science, Faculty of Engineering,
Tohoku University, Sendai 980, JAPAN
*Now at Central Research Lab., Sumitomo Mining Co.,Ltd.
Ichikawa 272, JAPAN

Abstract-Magnetic properties of $SmFe_{10}(Ti,M)_2$ melt-spun ribbons were studied, where M is V, Cr, Mn and Mo. The ribbons(M=V/Cr/Mo) quenched at 20m/s exhibit the high coercivities of 4.1-5.5 kOe. Annealing the ribbons quenched at 40m/s enhances their coercivities in the range of 5.9-10.0 kOe. In paticular, $SmFe_{10}(TiV)$ and $SmFe_{10}(TiCr)$ ribbons yield the coercivity of 10.0 kOe, and 7.9 kOe, respectively. This is the highest value among the reported melt-spun $ThMn_{12}$-type structure ribbons. Importance of Sm atmosphere during annealing is also demonstrated in minimizing the Sm evaporation from ribbons.

INTRODUCTION

$RE(Fe,M)_{12}$-type compounds with $ThMn_{12}$ crystal structure are promising candidates for permanent magnets because of their sufficient high magnetization and magnetocrystalline anisotropy[1,2]. Recently, high coercivities were observed in Sm-Fe-Ti systems[3]-[5], and in a Sm-Fe-V system[6]. It was reported that the high coercivities of 7.7 kOe or 6.5 kOe were observed in Sm-Fe-Ti-B or Sm-Fe-Ti-(Si,Al) ribbons, which always contained α-Fe after annealing[5]. The $SmFe_{10}V_2$ melt-spun ribbons had the coercivity of 7.8 kOe and also contained the cubic FeV phases[6]. The presence of α-Fe phases is reflected in the demagnetization curve as a "step".

We have reported that $SmFe_{10}(Ti,M)_2$ melt-spun ribbons have the possibilities to show the high coercivities[3,4]. The purpose of the present investigation is to further examine $SmFe_{10}(Ti,M)_2$ systems (M=V/Cr/Mn/Mo) for obtaining the high coercivity.

EXPERIMENTAL PROCEDURES

The compositions of studied alloys were selected as $SmFe_{10}(Ti_{1-X}M_X)_2$ (M=V,Cr,Mn,and Mo). The quenched ribbons were prepared by a single wheel technique under Argon atmosphere. The substrate surface velocity (Vs) of Cu wheel varies from 20m/s to 40m/s. The size of the fabricated ribbon in flake form is (10-70)μmx(1-1.4)mmx(15-100)mm. In our previous studies[3,4], it was shown that the optimum wheel speed for giving the high coercivities is 20m/s, and that the ribbons quenched excessively at 40m/s are suitable for further annealing. Over-quenched ribbons were annealed at 700°C-900°C for 30min in Sm atmosphere as shown in Fig.1. The ribbons were placed with small blocks of Sm in a quartz tube and were sealed in the vacuum of 10^{-2} Torr. The ribbons were ground into powders(under 0.15 mm). The powders mixed with molten parafin were solidified in a magnetic field of 12 kOe. The magnetic properties were measured with a vibrating sample magnetometer with the maximum applied field of 1.2 MA/m(15 kOe). The magnetic properties of some samples were measured after applying the pulse field of 4.0 MA/m(50 kOe). The crystal structures were studied by X-ray diffraction using FeKα radiation.

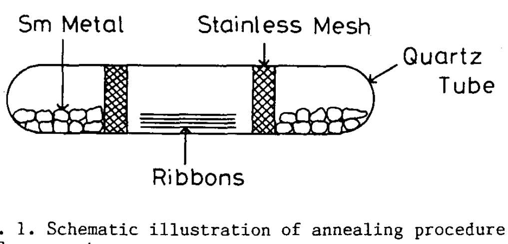

Fig. 1. Schematic illustration of annealing procedure in Sm atmosphere.

RESULTS AND DISCUSSIONS

Annealing of melt-spun ribbons in Sm atmosphere

It was reported that an α-Fe phase appeared in annealed melt-spun Sm-Fe-Ti ribbons[5], even though they observed no α-Fe phases in cast Sm-Fe-Ti ingots. The volume fraction of α-Fe phases increases with increasing the annealing temperature or time. We regard this phenomena as the evaporation of Sm from the melt-spun ribbons during annealing, because of the high vapor pressure of Sm. In order to clarify this problem, the ribbons were annealed in Sm atmosphere as shown in Fig. 1. Figure 2 shows the magnetic hysteresis loops of $SmFe_{10}(TiV)$ ribbons annealed at 800°C for 30min (a)in vacuum and (b) in Sm atmosphere. The magnetization curve of the ribbons annealed in vacuum has a knee in its shape, but that in Sm atmosphere has

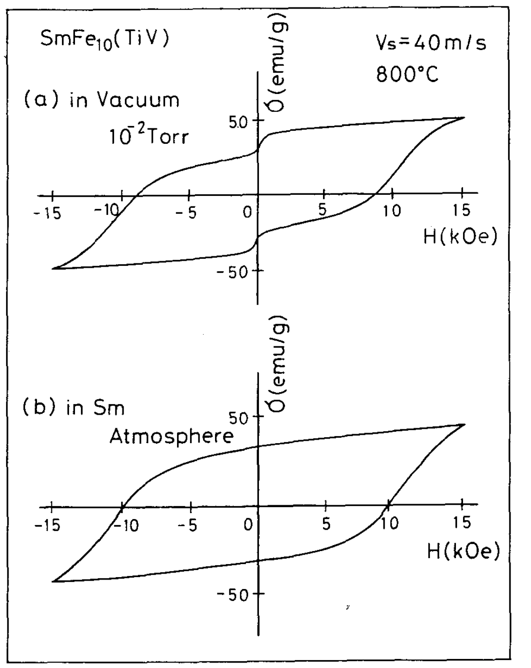

Fig. 2. The magnetic hysteresis loops of $SmFe_{10}(TiV)$ ribbons annealed at 800°C (a)in vacuum, and (b) in Sm atmosphere.

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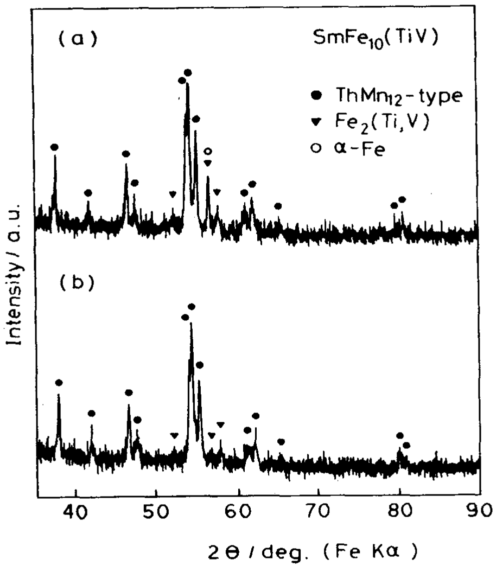

Fig. 3. The corresponding X-ray diffraction patterns of $SmFe_{10}(TiV)$ ribbons annealed at 800°C (a) in vacuum, and (b) in Sm atmosphere.

smooth shape. Figure 3 shows the corresponding X-ray diffraction patterns of the samples annealed (a) in vacuum and (b) in Sm atmosphere. The samples annealed in Sm atmosphere consist of mostly $ThMn_{12}$-type structure and the small fraction of $Fe_2(Ti,V)$ phases, but the samples annealed in vacuum contained α-Fe phases. The existence of α-Fe phases in ribbons gives the knee in the demagnetization curve. This result suggests that Sm atmosphere retards Sm evaporation from the samples and suppresses the formation of α-Fe phases during annealing. As a matter of fact, an α-Fe phase was not observed in the cast ingot or in the ribbons as quenched state. Hereafter, all samples were annealed by the procedure shown in Fig. 1, in minimizing the Sm evaporation from the ribbons.

Magnetic properties of $SmFe_{10}(Ti,M)_2$ ribbons (M=V/Cr/Mn/Mo)

In our previous studies, the optimum wheel speed for giving the high coercivity as spun-state was 20m/s. Table 1 shows the coercivities and magnetization intensities of $SmFe_{10}(TiM)$ melt-spun ribbons quenched at the wheel velocity of 20m/s. The samples with M=V, Cr, Mo have high coercivities over 4 kOe and magnetization values around 50 emu/g. But the sample with Mn has the coercivity lower than 1 kOe. X-ray diffractions suggest that this may be attributed to the incomplete crystallization of melt-spun ribbon.

Table 1 The coercivities and magnetizations of $SmFe_{10}(TiM)$ ribbons quenched at wheel velocity of 20m/s.

Composition	iHc(kOe)	σ(emu/g)
$SmFe_{10}(TiV)$	5.5	50
$SmFe_{10}(TiCr)$	5.2	51
$SmFe_{10}(TiMn)$	0.9	65
$SmFe_{10}(TiMo)$	4.1	47

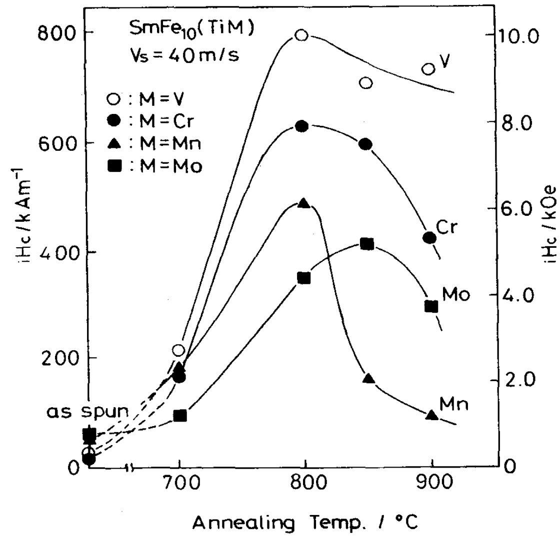

Fig. 4. Variation of the coercivity for $SmFe_{10}(TiM)$ (M=V/Cr/Mn/Mo) ribbons quenched at 40m/s, followed by annealing at 700°C-900°C.

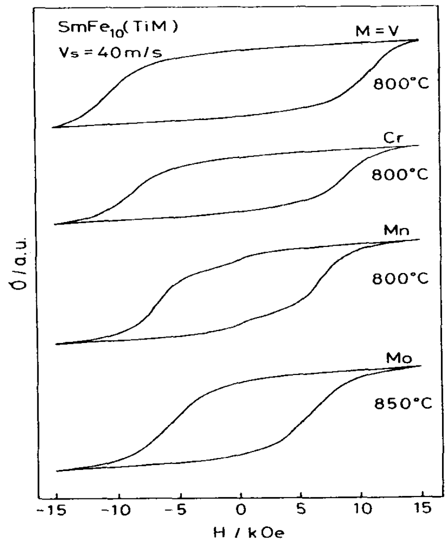

Fig. 5. The magnetic hysteresis loops of $SmFe_{10}(TiM)$ (M=V/Cr/Mn/Mo) ribbons annealed at 700°C-900°C.

The ribbons quenched excessively at 40m/s, are suitable for further annealing. Figure 4 shows the variation of the coercivities for $SmFe_{10}(TiM)$ (M=V/Cr/Mn/Mo) ribbons quenched at 40m/s, followed by annealing at 700°C-900°C for 30 min. The coercive force of the ribbons has the maximum value of 10.0 kOe for the samples with V, 7.9 kOe for Cr, and 6.1 kOe for Mn after annealing at 800°C, which is then the optimum temperature for annealing. The $SmFe_{10}(TiMo)$ ribbons have the maximum coercivity of 5.2 kOe after annealing at 850°C. The high coercivities over 6 kOe have been achieved in three alloys with V, Cr, and Mn. The corresponding magnetic hysteresis loops of $SmFe_{10}(TiM)$ ribbons (M=V/Cr/Mn/Mo) are shown in Fig. 5. The demagnetization curve of the annealed

$SmFe_{10}(TiMn)$ ribbons has the knee in its shape. But the rest of the ribbons shows smooth demagnetization curves. The corresponding X-ray diffraction patterns taken from the $SmFe_{10}(TiM)$ annealed ribbons (M=V/Cr/Mn/Mo) as shown in Fig. 6, indicate that the ribbons consist of mainly $ThMn_{12}$-type crystallized grains and the $Fe_2(Ti,M)$ phases without formimg o-Fe phases. Then the knee observed in the demagnetization curve of the annealed $SmFe_{10}(TiMn)$ would arise from the existence of $Fe_2(Ti,Mn)$ phase. Further studies are required to clarify why the $Fe_2(Ti,Mn)$ phases in $SmFe_{10}(Ti,Mn)_2$ ribbons give the knee in their demagnetization curves.

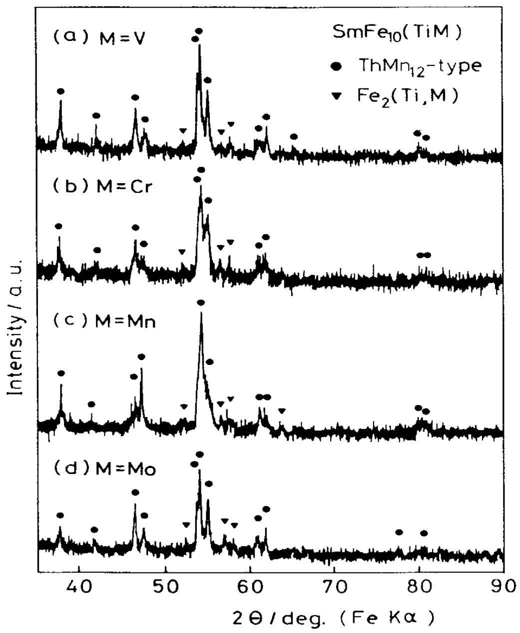

Fig. 6. The corresponging X-ray diffraction patterns of $SmFe_{10}(TiM)$ ribbons annealed at 800°C(M=V/Cr/Mn) or at 850°C(M=Mo).

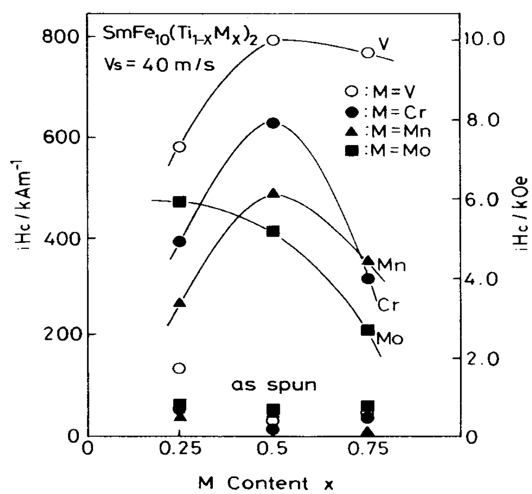

Fig. 7. Variations of the coercive force for $SmFe_{10}(Ti_{1-X}M_X)_2$ ribbons annealed at 800°C(M=V/Cr/Mn), or at 850°C(M=Mo).

Table 2 Magnetic properties of $SmFe_{10}(Ti,M)_2$ (M=V/Cr/Mn/Mo) ribbons measured by appling field of 15 kOe with or witout magnetizing with the pulse field of 50 kOe.

Composition	15kOe		50kOe	
	iHc(kOe)	σ(emu/g)	iHc(kOe)	σ(emu/g)
$SmFe_{10}(TiV)$	10.0	38	12.0	56
$SmFe_{10}(TiCr)$	7.9	56	8.1	65
$SmFe_{10}(TiMn)$	6.1	56	6.1	67
$SmFe_{10}(Ti_{0.75}Mo_{0.25})_2$	5.9	34	6.8	43

Figure 7 shows the variation of the coercive force of $SmFe_{10}(Ti_{1-X}M_X)_2$ ribbons annealed at 800°C(M=V/Cr/Mn) or at 850°C(M=Mo). The coercive force of the ribbons quenched at 40m/s before annealing is 100-800 Oe, independent of M content. But annealing enhances the coercivity of the ribbons. It was found that the optimum composition of the $SmFe_{10}(Ti_{1-X}M_X)_2$ ribbons which give the highest coercivity, is X=0.5 for all studied systems except $SmFe_{10}(Ti_{1-X}Mo_X)_2$ system. The reason why $SmFe_{10}(Ti_{0.5}M_{0.5})_2$ is the optimum composition is still not clear.

Table 2 summarizes the magnetic properties of $SmFe_{10}(Ti,M)_2$ (M=V/Cr/Mn/Mo) obtained in the present study, with the maximum applied field of 1.2 MA/m(15 kOe). The magnetic properties measured after applying the pulse magnetic field of 4.0 MA/m(50 kOe), are also shown. The coercive force of $SmFe_{10}(TiV)$ ribbons increases to 12 kOe, the magnetization intensity becomes 56 emu/g. This coercive force is the highest value among the reported $ThMn_{12}$-type structure ribbons.

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